National Aeronautics and Space Administration

The High End Computing Capability Project: Excellence at the Leading Edge of Computing

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Introduction

- NAS has stellar history of amazing accomplishments, drawing from synergy between high end computing (HEC) and modeling and simulation (M&S)
- NAS has earned national and international reputation as a pioneer in the development and application of HEC technologies, providing its diverse customers with world-class M&S expertise, and state-of-the-art supercomputing products and services
- HECC has been a critical enabler for mission success throughout NASA – it supports the modeling, simulation, analysis, and decision support activities for all four Mission Directorates, NESC, OCE, and OS&MA
- HECC Mission: *Develop and deliver the most productive HEC environment in the world, enabling NASA to extend technology, expand knowledge, and explore the universe*
- SCAP model of baseline funding + marginal investment has been immensely successful and has had a positive impact on NASA science and engineering
  - Baseline funding provides “free” HECC resources and services (MDs select own projects, determine priorities, and distribute own resources)
  - Marginal investments from ARMD, ESMD, and SMD demonstrate current model has strong support and buy-in from MDs

HEC Characteristics

- HEC, by its very nature, is required to be at the leading edge of computing technologies
  - Unlike agency-wide IT infrastructure, HEC is fundamentally driven to provide a rapidly increasing capability to a relatively small but very diverse and critical set of customers
  - Requires regular, frequent, highly-specialized hardware and systems software refreshes to leverage the latest technologies
  - Requires regular, specialized application software research and development to optimally exploit new architectures to efficiently solve complex NASA problems
  - Requires accessibility by remote collaborators who are not NASA employees
- NASA HEC strategy cannot only rely on industry or market-driven advances in underlying technologies
  - HEC must take advantage of multiple highly dynamic and somewhat speculative technology domains
  - NASA requirements often drive new supercomputer architectures and technology advances that are being / will be developed by industry
- Key characteristics of successful HEC governance in other parts of the Federal Government (DOE, DoD, NSF, etc.)
  - “Corporate level” funding with built-in capital refresh budgets
  - Robust customer program engagement in governance and management
  - Strong infrastructure and facilities support

NAS Creation

- In 1976, Ames Director Hans Mark tasked group led by Ron Bailey to explore the concept of simulation-centric design and engineering by executing computational fluid dynamics (CFD) models on supercomputers to transform U.S. aerospace from costly and time-consuming wind-tunnel based processes
  - *Led to formation of Numerical Aerodynamic Simulator (NAS) Projects Office in 1979*
- Simultaneously, a user interface group of CFD leaders from industry, government, and academia formed to guide requirements for the NAS concept and provide feedback on evolving supercomputer feasibility studies
  - *At the conclusion of this activity in 1982, NASA changed the NAS approach from a focus on purchasing a special-purpose supercomputer to an on-going Numerical Aerodynamic Simulation (NAS) Program to provide leading-edge computational capabilities based on an innovative network-centric environment*
- On Feb 8, 1983, Program Plan signed and NAS came into existence as NASA's bold initiative in simulation-based aerospace vehicle design and stewardship
  - *Many on-going activities worldwide in Simulation-Based Engineering and Science (SBE&S)*

NAS Early Accomplishments

- **1984:**
  - First UNIX-based supercomputer Cray X-MP-12 (210 MFlops peak) arrives
  - SGI IRIS 1000 graphics terminals dramatically transform post-processing and visualization of CFD results
- **1985:**
  - March 14: Groundbreaking for NAS facility and multi-disciplinary innovation environment, bringing together CFD experts and computer scientists
  - First 4-processor Cray-2 (1.95 GFlops peak) – sustained performance of 250 MFlops makes it the world's most powerful supercomputer at the time
  - NASnet – high-speed long-haul TCP/IP network connects users to NAS
- **1986:**
  - NAS transitions from Projects Office to full-fledged Division
  - LaRC researchers use NAS to understand, analyze Challenger disaster (failure of the O-ring) – largest 3D structural simulation in the world to date
- **1987:**
  - General Dynamics use Cray-2 to obtain Navier-Stokes solutions for F-16
  - NAS partners with DARPA and UC Berkeley in RAID (Redundant Array of Inexpensive Disks) project – leads to industry standard in 1992
  - March 9: NAS facility dedicated by NASA Administrator James Fletcher

NAS Accomplishments (1988 – 1992)

- **1988:**
  - Second Cray-2 arrives, doubling NAS supercomputing capability
  - 8-processor Cray Y-MP (2.54 GFlops peak) meets goal of 1 GFlops sustained performance; Cray-2 used by DoD at NAS for classified computing
  - 16,000-processor CM-2 (14.3 GFlops peak) initiates massively parallel computing research within NASA
- **1989:** StorageTek 4400 cartridge tape robots (2.2 TBytes) reduce retrieval time from 4 mins to 15 secs, become first UNIX-base storage system in 1990
- **1990:** Interactive 3D VWT (Virtual Wind Tunnel) tool uses virtual reality technology to enable users visualize, explore, analyze CFD simulation results
- **1991:**
  - NPB (NAS Parallel Benchmarks) developed – becomes industry standard for comparing different systems and still widely used today
  - 128-processor Intel iPSC/860 (7.68 GFlops peak) runs largest incompressible Navier-Stokes simulation to date
  - OVERFLOW released, becoming the first general-purpose NASA CFD code for overset grid systems, resulting in production-level capability
- **1992:** NAS supports U.S Navy, McDonnell Aircraft to demonstrate ability of CFD to predict aerodynamic loads on F/A-18 and reduce expensive wind tunnel tests

NAS Accomplishments (1993 – 1997)

- **1993:** 16-processor Cray C90 (15.4 GFlops peak) arrives
- **1994:**
  - NAS and NERSC release PBS (Portable Batch System), improving job scheduling and resource management – commercialized in 1998
  - PLOT3D awarded 4th largest NASA Space Act Award ever for revolutionizing scientific visualization and analysis of 3D CFD solutions
  - 160-processor IBM SP2 (42.6 GFlops) arrives – 300 users across NASA
  - INS3D (Incompressible N-S) wins NASA Software of the Year Award
- **1995:**
  - FAST (Flow Analysis S/W Toolkit) wins NASA Software of the Year Award
  - NAS changes name to Numerical Aerospace Simulation Division
- **1996:** NAS and LaRC create NASA Metacenter – first evidence of grid computing
- **1997:**
  - First shared-memory 64-processor SGI Origin2000 system
  - IPG (Information Power Grid) launched to seamlessly integrate computing platforms, data storage, networks, and analysis software across NASA
  - Nanotechnology group wins Feynman Prize for Theoretical Work

NAS Accomplishments (1998 – 2002)

- **1998:** CAPO automated tool simplifies and accelerates tedious process of parallelizing large serial codes
- **1999:** CGT (Chimera Grid Tools) for overset grid generation released – currently licensed to more than 500 organizations nationwide
- **2000:**
  - 512-processor SGI Origin2800 used by LaRC to analyze thermodynamic conditions for NASA/Boeing X-37 experimental launch vehicle reentry
  - MLP (Multi-Level Parallelism) developed to take advantage of shared-memory multiprocessor supercomputing architectures
- **2001:**
  - Life-saving DeBakey Ventricular Assist Device (VAD) developed by NAS, JSC, and MicroMed wins NASA Commercial Invention of the Year
  - 1024-processor SGI Origin3800 (819 GFlops peak) installed
  - NAS changes names to NASA Advanced Supercomputing Division
- **2002:**
  - Cart3D (co-developed with NYU) wins NASA Software of the Year Award
  - hyperwall (graphics cluster and LCD panel wall) designed and developed to enable users view complex simulation and observational datasets
  - AeroDB database-centric software system automates CFD processes – extensively used by Shuttle Program for rapid engineering analysis

HEC Rediscovered (2003)

- Success of Japan's *Earth Simulator* leads U.S. Federal Government to form High End Computing Revitalization Task Force (HECRTF) to increase nation's supercomputing capability and improve inter-agency coordination – NAS is heavily involved
- HEC and M&S demonstrate positive impact on Columbia (STS-107) Accident Investigation Board (CAIB) studies
- NASA has critical requirement for HEC and M&S to support Shuttle Return-to-Flight (RTF)
- NASA unable to satisfy all mission-critical computational requirements due to insufficient capability
- World's first 512-processor SSI (Single System Image) SGI Altix 3700 (3.1 TFlops peak) (*Kalpana*) successfully deployed at NAS

Columbia Arrives (2004)

- Multiple Federal agencies charter study to assess HEC R&D in Japanese government, industry, and academia – NAS provides expert panelist
- NASA pursues Nation's Vision for Space Exploration (VSE)
- Agency leadership, recognizing the immense potential of M&S to help achieve VSE, funds High End Computing Columbia (HECC) project at NAS (HECC name later changed to High End Computing Capability)
- Intel, SGI, and other vendors extremely motivated to demonstrate the effectiveness of their innovative technologies
- NASA-Industry partnership cost-effectively acquires and installs *Columbia* supercomputer (10240 processors, 63 TFlops peak) in record 120 days, increasing NASA's aggregate computational capability by 10X
- *Columbia* ranked #2 in the world, with a sustained Linpack rating of 51.9 TFlops
- Combined with auxiliary resources and end-to-end services, NAS provides a balanced productive environment to support a widely distributed user base from all NASA Enterprises (later reorganized as Mission Directorates)
- Each NASA Enterprise assessed a share of annual cost, and receives baseline resources and services in return (based on historical usage, future needs)
- NASA Programs can provide additional funds to augment their share of resources and services while leveraging SCAP-funded infrastructure

SCAP Established (2006)

- NASA forms Shared Capability Assets Program (SCAP) to ensure vital assets and capabilities shared by multiple Mission Directorates are healthy and sustained (name later changed to Strategic Capabilities Assets Program)
- HECC becomes one of the first two SCAP assets, cementing NASA's long-term commitment to supercomputing as an essential resource for broad mission success
- NAS releases NTR (NAS Technology Refresh) RFI, initiating the process of enhancing HEC capability to keep pace with NASA's growing computational demands

HECC Reinvigorated (2007 – 2008)

2007

- As part of the NTR effort, HECC procures two new supercomputers:
  - 640-core IBM POWER5+ (4.8 TFlops peak)
  - 2048-core SGI Altix 4700 (13 TFlops peak) – largest SSI system ever built
- To meet increasing computational demand, ESMD funds purchase of two 1024-core SGI Altix 4700 (13 TFlops peak)
- To enable path finding research, ARMD funds purchase of 4096-core SGI Altix ICE cluster (43.5 TFlops peak)

2008

- NTR process selects SGI Altix ICE 8200 as next major NASA supercomputer
- Significant electrical, cooling, and network upgrades in N258 and N233A
- hyperwall-2 goes live as the highest resolution display system in the world
- Pleiades debuts at #3 with a sustained performance of 487 Tflops

HECC Reinvigorated (2009 – Present)

2009

- Spectra Logic tape system drastically reduces cost of archive storage and frees up significant floor space
- Rolling software update process saves millions of valuable compute hours
- SMD uses ARRA funds to purchase 9216 “Nehalem” cores for Earth Science

2010

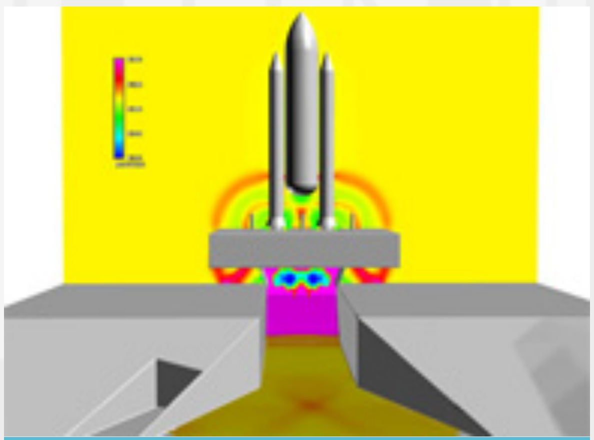
- HECC filesystem expanded by 3 Pbytes
- Pleiades augmented by 1024 Nehalem and 27,648 Westmere cores
- Pleiades ranked #6 with a sustained performance of 772.7 Tflops

2011

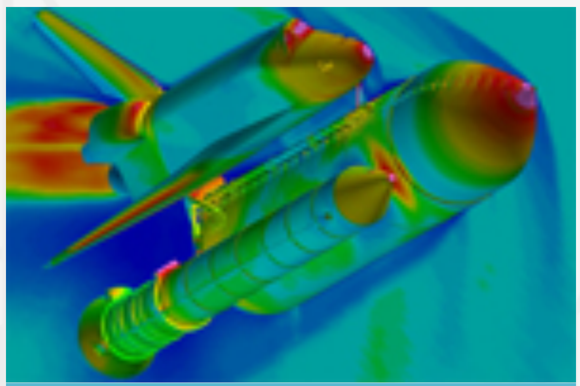
- HECC filesystem expanded by 6 Pbytes
- Pleiades augmented by 26,112 Westmere cores
- Pleiades ranked #7 with a sustained performance of 1.088 Pflops
- Pleiades augmented by 768 Westmere cores and 32,768 Nvidia M2070 cores

NASA's HEC Requirements: Capacity

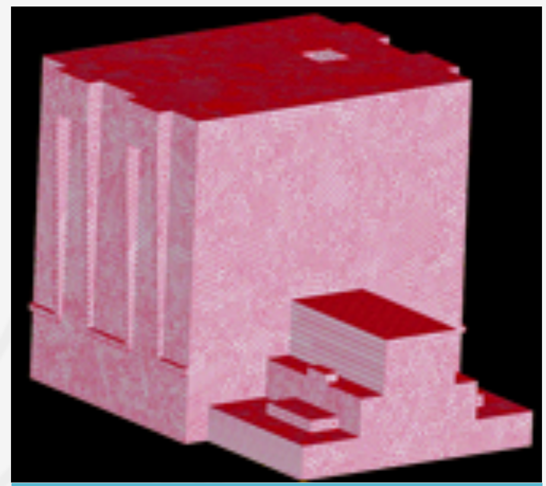
ESMD and SOMD (engineering-related work) require HEC resources that can handle large numbers of relatively-low CPU-count jobs with quick turnaround times



Launch Pad flame trench simulations



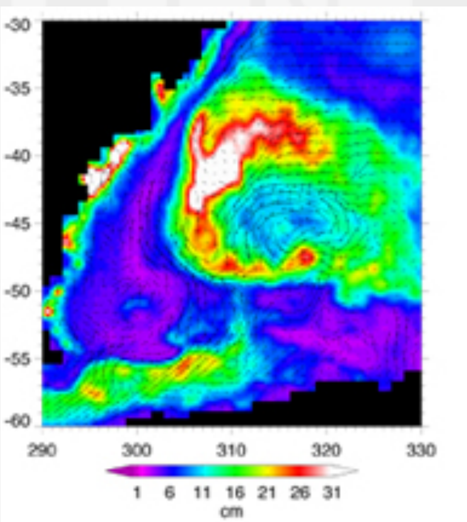
Space Shuttle debris transport analysis



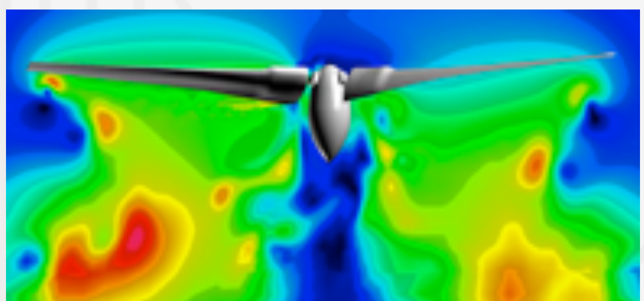
Vehicle Assembly Building safety assessment

NASA's HEC Requirements: Capability

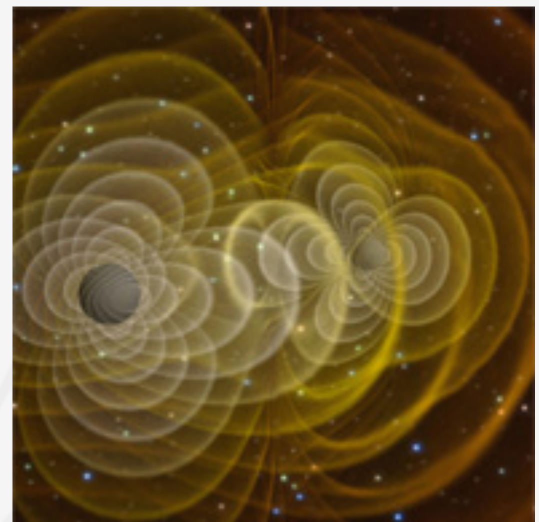
ARMD and SMD (aeronautics- and science-related work) require HEC resources that can handle high fidelity relatively-large CPU-count jobs with minimal time-to-solution



High-resolution global ocean & sea-ice data synthesis



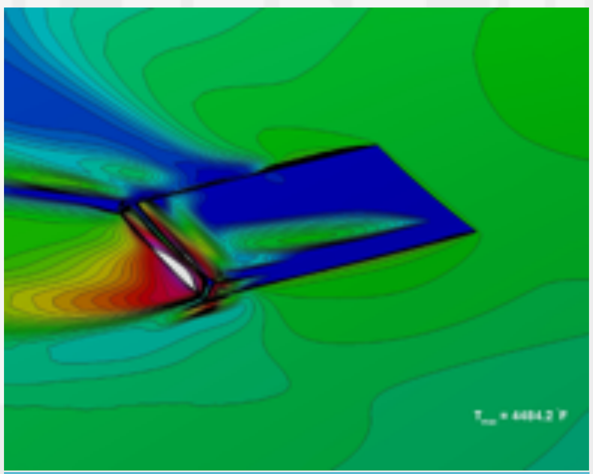
CFD simulations of rotary wing aerodynamics



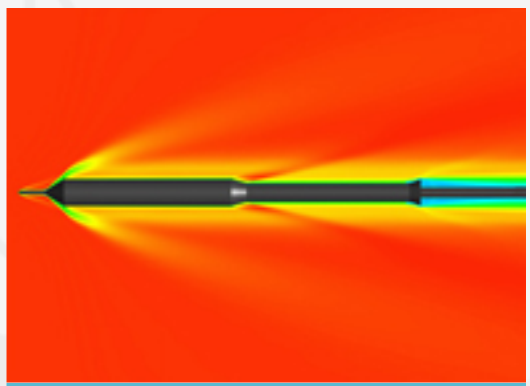
Simulating merging black holes and predicting their gravitational wave signatures

NASA's HEC Requirements: Time-Critical

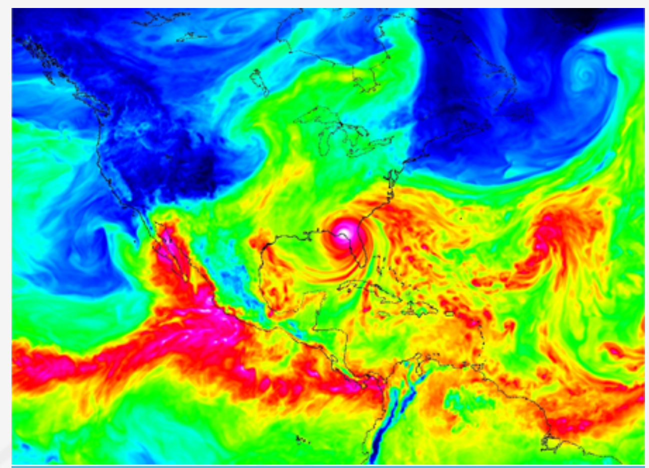
NASA also has need for HEC resources that can handle time-sensitive mission-critical applications on demand (maintain readiness)



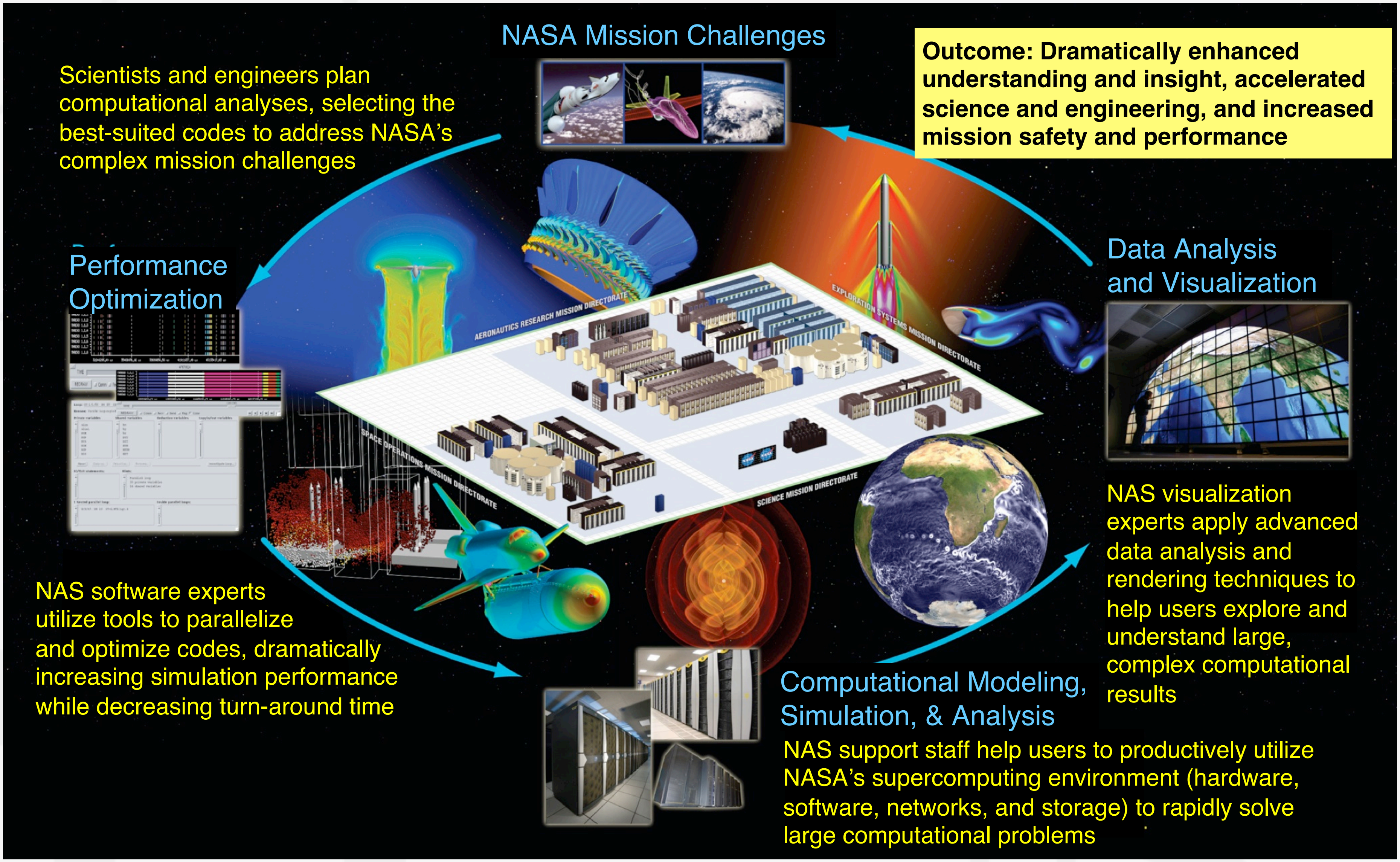
Keep Shuttle flying safely



High-fidelity simulations supporting crew risk assessment on abort



Hurricane prediction


NASA Mission Challenges
Outcome: Dramatically enhanced understanding and insight, accelerated science and engineering, and increased mission safety and performance
Scientists and engineers plan computational analyses, selecting the best-suited codes to address NASA's complex mission challenges
Performance Optimization
Data Analysis and Visualization
AERONAUTICS RESEARCH MISSION DIRECTORATE
EXPLORATION SYSTEMS MISSION DIRECTORATE
SPACE OPERATIONS MISSION DIRECTORATE
SCIENCE MISSION DIRECTORATE
NAS visualization experts apply advanced data analysis and rendering techniques to help users explore and understand large, complex computational results
NAS software experts utilize tools to parallelize and optimize codes, dramatically increasing simulation performance while decreasing turn-around time
Computational Modeling, Simulation, & Analysis
NAS support staff help users to productively utilize NASA's supercomputing environment (hardware, software, networks, and storage) to rapidly solve large computational problems

World-Class Supercomputing Capability: Enabling NASA Science and Engineering

Computing Systems

- Pleiades – 1366 TFlops peak
  - 111,104-core SGI Altix ICE
  - 3 generations of Intel Xeon processors: Harpertown, Nehalem, Westmere
  - Debuted as #3 on TOP500 in 11/08; now #7
  - 64 graphics enhanced nodes
- Columbia – 29 TFlops peak
  - 4,608-processor SGI Altix (Itanium2)
  - Debuted as #2 on TOP500 in 11/04
- hyperwall-2 – 146 TFlops peak
  - 1,024-core (Opteron), 128-node GPU cluster
  - Large-scale rendering, concurrent visualization

Balanced Environment

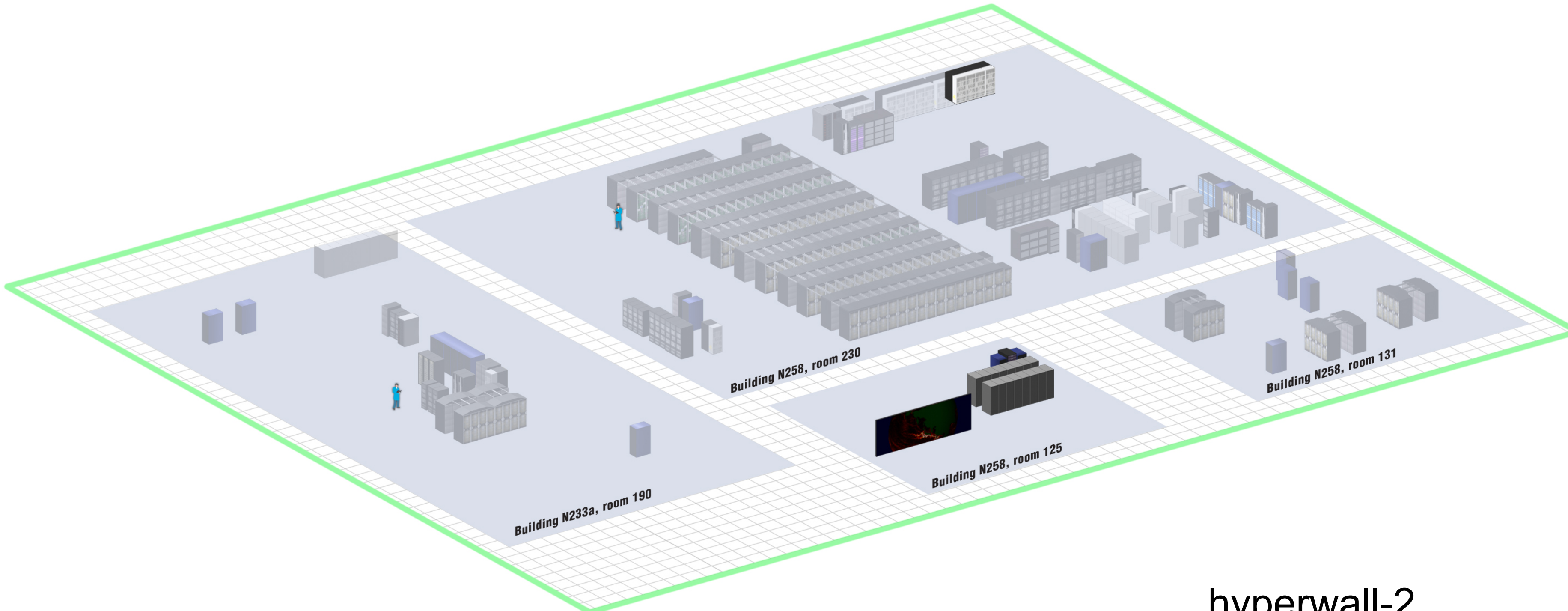
- Storage: 9.3 Pbytes RAID disk; 50 PBytes tape
  - Archiving about 1PByte per month
  - Usage growth ~1.9X/year since 2000
- WAN: 10 Gb/s to some Centers and high-bandwidth external peering
  - Transferring 150TB/month to distributed users
  - Usage growth ~2.7X/year since 2005

SBU: Standard Billing Unit – used to normalize the Node-hours from different systems

- **Resources enable broad mission impact**
  - MDs select projects, determine allocations
  - Approx 450 science & engineering projects
  - About 1000 user accounts
  - Typically 200 to 500 jobs running at any instant
  - Demand for computing cycles extremely high
  - About 4 million SBUs delivered each month
- **HEC demand & resources growing rapidly**
  - NASA HPC requirements projected to multiply by at least 4X every 3 years (Moore's Law)
  - Capacity growth ~1.8X/year since 1988

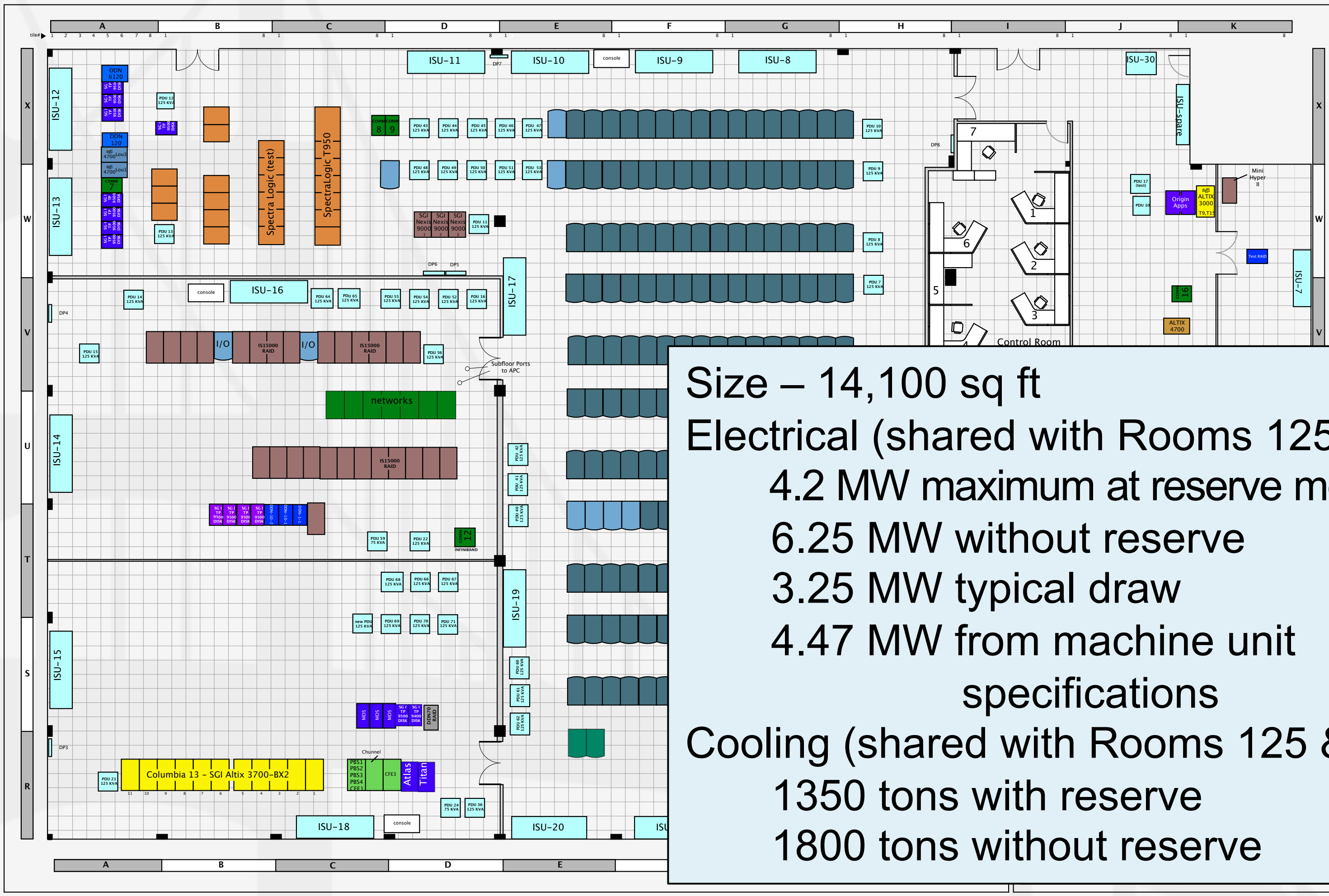
COMPUTING RESOURCES

HECC Computer Floors



hyperwall-2

N258, Room 230



Size – 14,100 sq ft

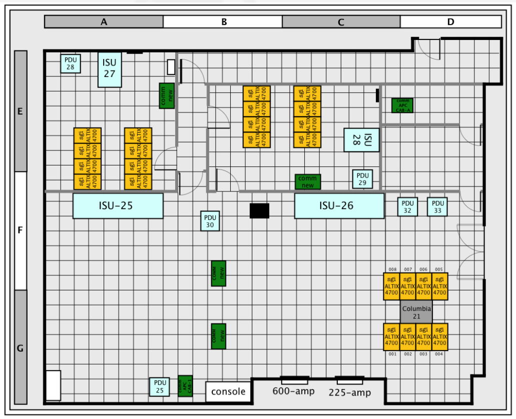
Electrical (shared with Rooms 125 & 131)

- 4.2 MW maximum at reserve mechanical
- 6.25 MW without reserve
- 3.25 MW typical draw
- 4.47 MW from machine unit specifications

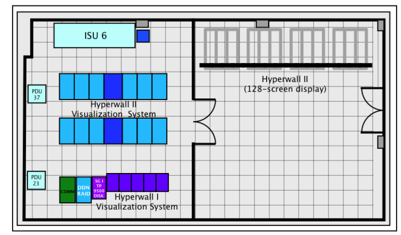
Cooling (shared with Rooms 125 & 131)

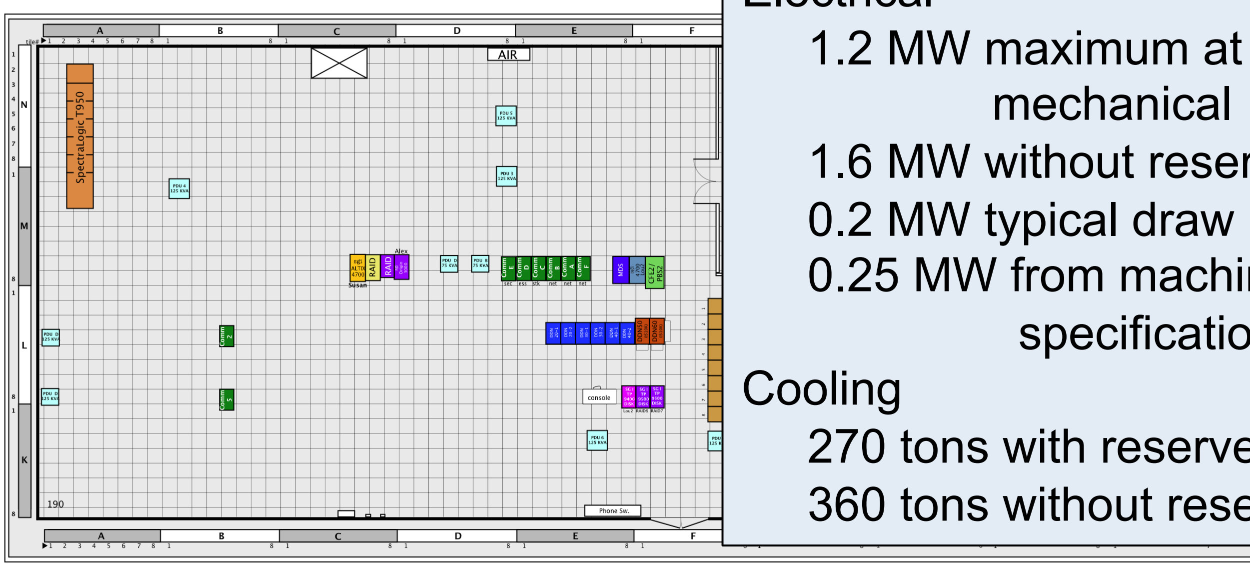
- 1350 tons with reserve
- 1800 tons without reserve

N258, Rm 125/131 – N233A, Rm 189/190



N258/131
Size – 2,600 sq ft





N233A, Rooms 189 & 190
Size – 8,600 sq ft
Electrical
- 1.2 MW maximum at reserve mechanical
- 1.6 MW without reserve
- 0.2 MW typical draw
- 0.25 MW from machine unit specifications

Cooling
- 270 tons with reserve
- 360 tons without reserve


Pleiades

Pleiades – Specifics

- 184 SGI Altix ICE Racks
  - 92 racks of 8200EX with Intel Xeon processor E5472 (Harpertown):
    565 TF; 47.1 TB; 2,650 SBUs
  - 20 racks of 8200EX with Intel Xeon processor E5570 (Nehalem):
    120 TF; 30.7 TB; 1,024 SBUs
  - 70 racks of 8400EX with Intel Xeon processor E5670 (Westmere):
    630TF; 107.5 TB; 4,480 SBUs
  - 2 racks of Coyote with Intel Xeon processor E5670 (Westmere) and Nvidia M2090 graphics processors: 50TF; 1.5 TB; 64 SBUs (note, GPUs are not characterized and are not counted)
- 23,488 processors (144,640 cores)
  - 11,776 quad-core Harpertown 3.0 GHz processors (47,104 cores)
  - 2,560 quad-core Intel Nehalem 2.93 GHz processors (10,240 cores)
  - 8,960 six-core Intel Westmere 2.93 GHz processors (53,760 cores)
  - 64 512-core Nvidia M2090 Tesla 1.2998 GHz graphics processors (32,768 cores)

- 11,648 nodes (dual-socket blades)
- 64 nodes (dual-socket + GPU)
- 8 Login nodes
- Two 1 TB Home filesystems (total 2 TB)
- 9.3 PB Storage (7 filesystems)
- Interconnect
  - Internode: Dual-plane partial 11D hypercube (DDR and QDR)
  - Gigabit Ethernet Management Network

Columbia – Specifics

- 29 TF constellation-class supercluster
- 4 SGI Altix 4700 nodes with Intel Itanium 1.6 GHz processors
  - One 512-core node with Montecito
  - Two 1,024-core nodes with Montecito
  - One 2,048-core with Montvale
- Interconnect
  - Intranode: NUMALink (enable large SSI)
  - Internode: Switched 4x SDR InfiniBand for communications
  - 10 Gb Ethernet for primary data movement
  - 1 Gb Ethernet for secondary data movement
  - 1 Gb Ethernet for shared filesystem heartbeat
  - 1Gb Ethernet for Management
  - Fibre Channel network for storage access

- 2 Login nodes
- 8 273 GB Home filesystems (total 2 TB)
- 1 PB Storage (one shared and multiple local filesystems)

Advanced Visualization: hyperwall-2 and CV

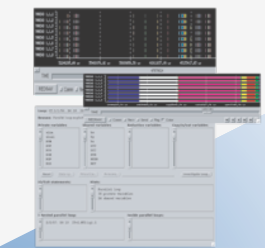
- Supercomputer-scale visualization system to handle massive size of simulation results and increasing complexity of data analysis
  - 8x16 LCD tiled panel display (23 feet x 10 feet)
  - 245 million pixels
  - Debuted as #1 resolution system in the world
  - In-depth data analysis and software
- Two primary modes
  - Single large high-definition image
  - Sets of related images (e.g. parameter study)
- High-bandwidth to HEC resources
  - *Concurrent Visualization:* Runtime data streaming allows visualization of every simulation timestep – ultimate insight into simulation code and results with no disk i/o
  - *Traditional Post-Processing:* Direct read/write access to Pleiades filesystems eliminates need for copying large datasets
- GPU-based computational acceleration R&D for appropriate NASA codes

HECC SERVICES

HECC Project conducts work in four major technical areas

Supercomputing Systems

Provide computational power, mass storage, and user-friendly runtime environment through continuous development and deployment of management tools, IT security, systems engineering



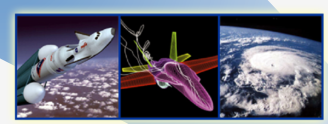
Application Performance and User Productivity

Facilitate advances in science and engineering for NASA programs by enhancing user productivity and code performance of high-end computing applications of interest

HECC

Data Analysis and Visualization

Create functional data analysis and visualization software to enhance engineering decision support and scientific discovery by incorporating advanced visualization technologies and displays



Networking

Provide end-to-end high-performance networking to meet massive modeling and simulation data distribution and access requirements of geographically dispersed users

Supporting Tasks

- Facility, Plant Engineering, and Operations: Necessary engineering and facility support to ensure the safety of HECC assets and staff
- Information Technology Security: Provide management, operation, monitoring, and safeguards to protect information and IT assets
- User Services: Account management and reporting, system monitoring and operations, first-tier 24x7 support
- Internal Operations: NAS Division activities that support and enhance the HECC Project areas

A Model for Success

- Provide support across the entire spectrum of users and their diverse requirements
- Focus on optimization of science and engineering enabled by high-end computing
  - Install hardware that provides world-class cost performance in capability, capacity, and time-critical computing
  - Team with scientific and engineering communities to ensure that their application codes achieve optimal performance in the targeted environment
  - Invest in a comprehensive set of tools that enables full understanding of system and application performance
  - Provide data analysis and visualization tools and support that enable the exploration of huge data-sets, providing insights that were not previously possible

NASA's Premier Supercomputing Facility

- HECC project was formed to provide integrated systems and services to meet the diverse computational requirements of a scientific, technical agency
- The group structure set up under HECC project is structured to amplify each of the individual group services and consolidate them into an integrated environment that meets the specific needs of a broad user community
- The integrated environment is designed to allow tight communication between multiple processes with access to large amounts of information and data
- The primary focus of all staff is to enable scientific and engineering discoveries for the user community

A Unique Discovery Environment

- Ability to run hundreds of jobs ranging from tens to tens of thousands of tightly coupled cores exploiting the largest InfiniBand cluster in the world
- Access to large shared memory systems, allowing jobs to process 4TB of data in a shared memory
- Innovative management techniques, providing the ability to add and/or remove components without bringing the system down
- Heterogeneous connectivity through InfiniBand to hyperwall for concurrent visualization
- User account on HECC asset provides computing, storage, code porting and scaling, application enhancement, data analysis, visualization, and network support

Supercomputing Systems

- Baseline Services
  - Systems Engineering: Design complex systems (e.g. Columbia, Pleiades), state-of-the-art data archive, and the integration of supercomputers, storage, and hyperwall into a cohesive whole
  - System Management: At the leading edge, problems occur that have never been seen before; daily operations focused on results
  - Systems and Security Integration: Constant compliance with a changing security environment while maintaining technical integrity and performance is key on systems that are international targets
  - Management Tools: Where possible, tools are procured, but development essential to manage a world-class supercomputing environment
- Additional Services
  - Procurement Support: Facilitate the acquisition, integration, and operation of additional assets to meet specific MD requirements
  - Technology Awareness: Ongoing assessment of current and near-future state of HEC via close interactions with industry

Application Performance and Productivity

- Baseline Services
  - Performance Optimization: HECC computer science experts work closely with application owner and domain expert to effectively exploit the system, maximizing code performance (often by an order of magnitude) and impact
  - Scientific Consulting: 2nd tier support for users' problems with utilizing the system from scripts through compilers and tools
  - Advanced Technologies: Through both tool assessment and utilization and testing of new system technologies, the focus is on improving NASA's return on investment
- Additional Services
  - Long-term performance optimization
  - Ongoing assessment of current and near-future state of software and programming environment via close interactions with industry and academia

Data Analysis and Visualization

- Baseline Services
  - Concurrent Visualization: The development of the combined hyperwall / Pleiades (Columbia) environments has enabled an advancement in data analysis, enabling high-temporal insights without a huge growth in storage or degradation in performance
  - Traditional Post-Processing Visualization: Still an essential component of data analysis, we employ a wide variety of scalar and vector field visualization techniques for point-based and structured/unstructured/adaptive mesh data
- Additional Services
  - Group works very closely with subset of users to provide long-term support in very data intensive applications
  - Ongoing assessment of current and near-future state of graphics hardware and visualization techniques via close interactions with industry and other labs

Networking

- Baseline Services
  - Partnering with major network communities facilitates collaboration with academic and other agencies
  - End-to-end support provided to any user to resolve network issues that would enhance HECC work environment
    - Remote LAN team(s)
    - NISN
    - WAN service provider
    - Remote system administrator
- Additional Services
  - None

User Support

- Baseline Services
  - 24x7 Control Room provides 1st level support to almost 1000 users
    - Handle questions concerning compute environment
    - Help users establish accounts
    - Contact other expert support as required
    - Notify management when issues arise
  - 24x7 Control Room monitors HECC resources
    - 4 computer floor in 2 buildings
    - Over $75M of assets
    - 3 major computer systems, RAID, archive, peripherals
    - Over 500 racks of equipment
- Additional Services
  - 24x7 Control Room for other NASA entities (e.g. SOC)

IT Security

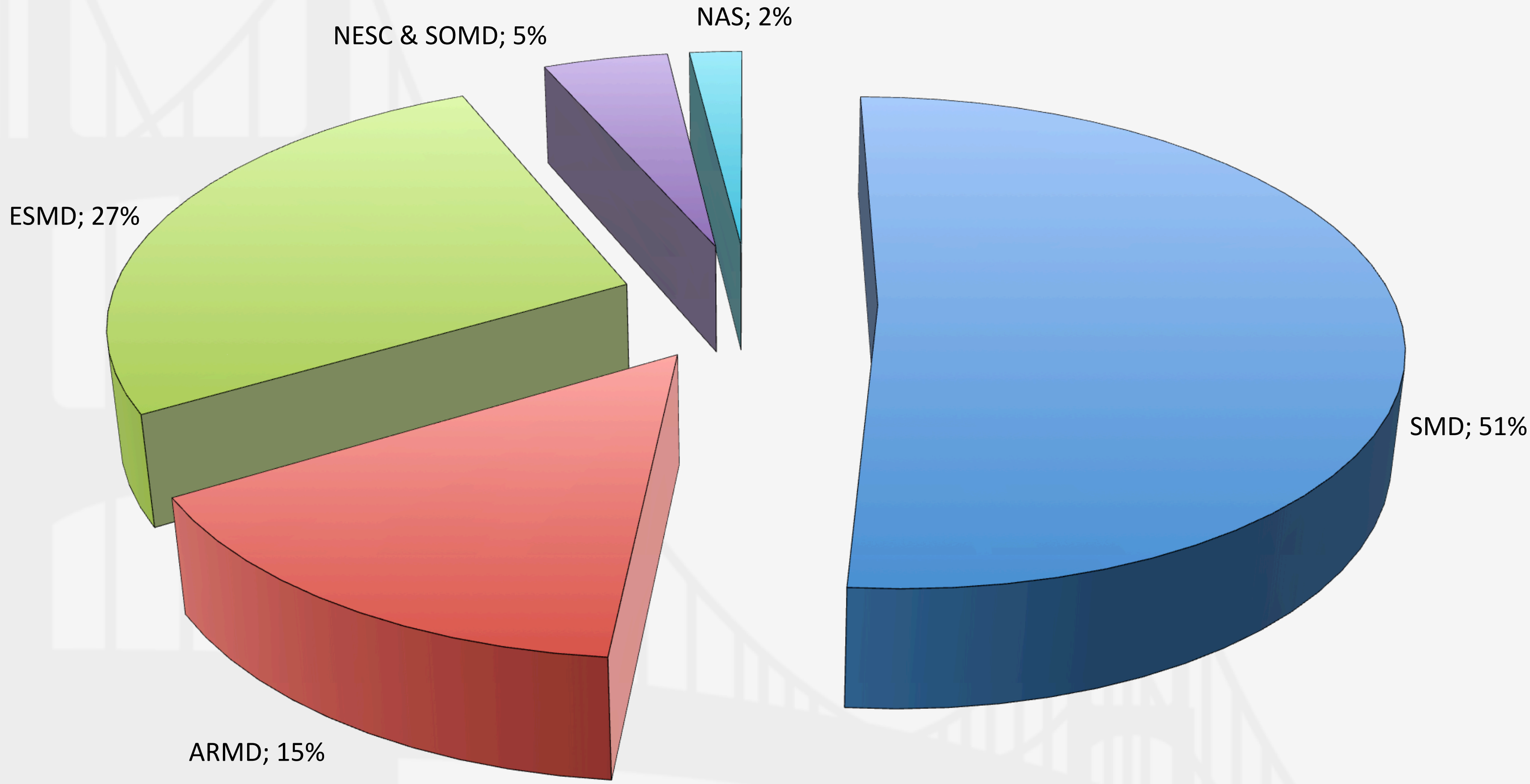
- ## Baseline Services
  - Ensure secure computing environment
    - Tension maintained between technical performance and protection
    - Focus on strong border control
      - Secure Front Ends
      - Separate Foreign National Enclave
      - Secure Unattended Proxy
    - Constant monitoring
    - Compliance
      - NPR 2810.1A Security of Information Technology
      - NIST SP 800-53 Rev 3 Recommended Security Controls for Federal Information Systems and Organizations
- ## Additional Services
  - None

Supported by NAS Division Assets

- Facilities
  - Electrical and HVAC support for evolving computational environment
  - Installation support
  - Property management
  - Shipping and Receiving
  - Compliance with all national, state, and agency policies
- Outreach
  - Conference support
  - Web content management
  - Publications and media responses
- Engineering Servers and Services
  - Server support
  - Desktop support

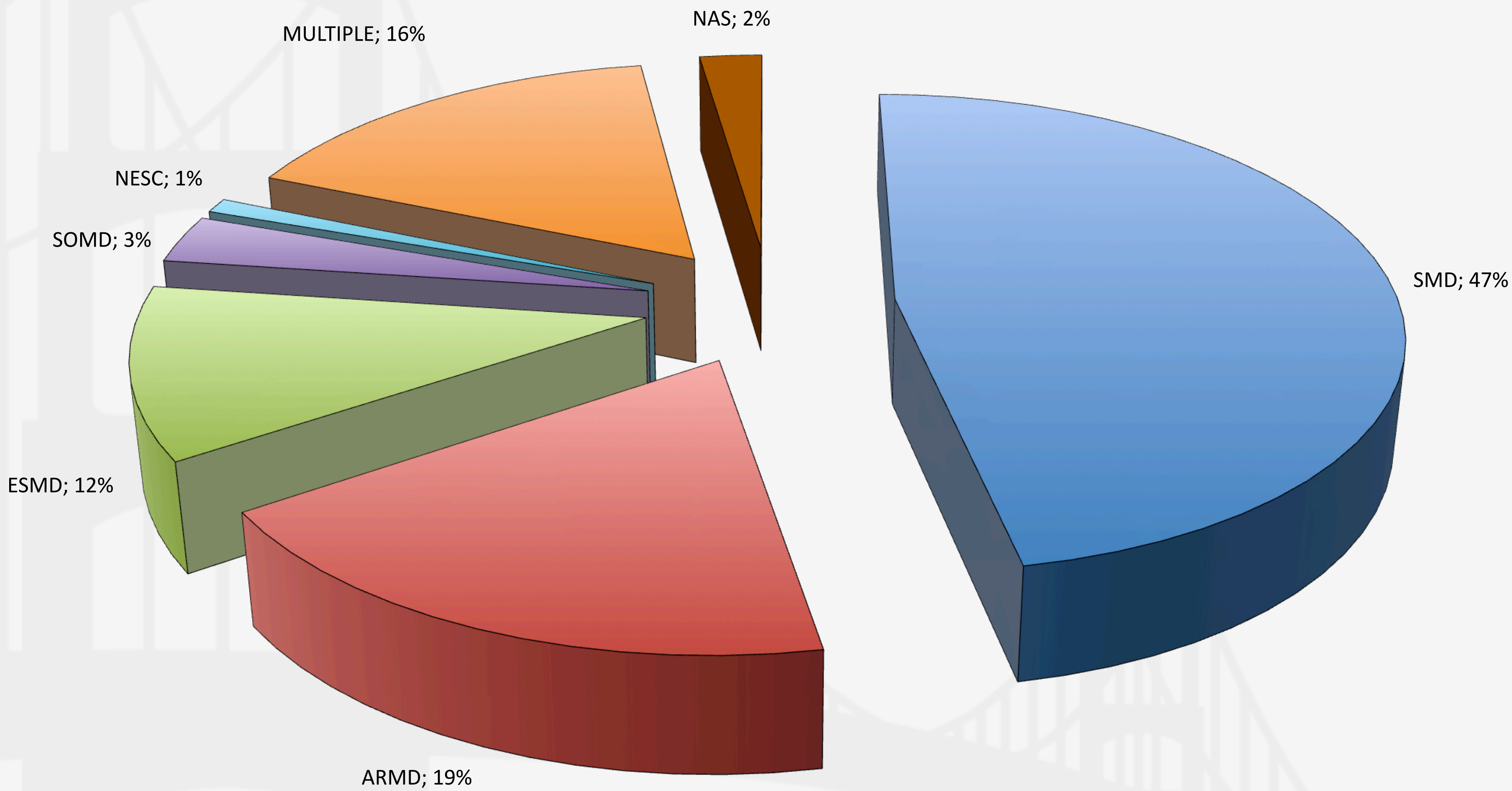
RESOURCE UTILIZATION

Distribution of Usage on NAS Systems (in Pleiades Westmere Node Hours)
6/1/2010 to 5/31/2011



SMD	ARMD	ESMD	NESC & SOMD	NAS
21,371,979	6,231,059	11,250,067	1,913,865	801,567

Affiliation of 1075 Users by Mission Directorate



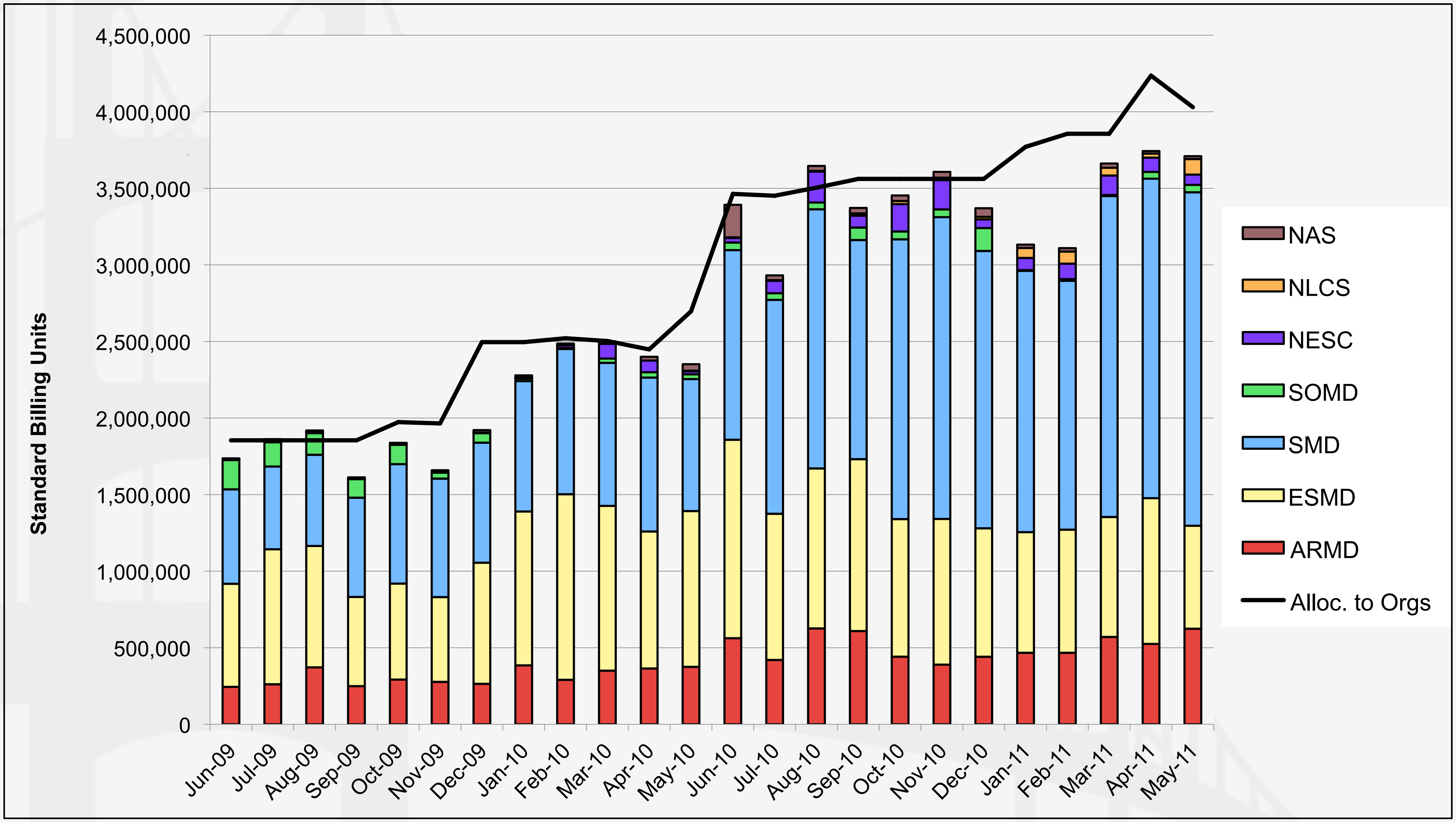
SMD	ARMD	ESMD	SOMD	NESC	MULTIPLE	NAS
506	200	124	35	10	176	25

User Location

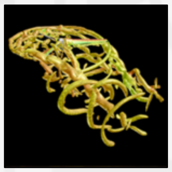
CT – 1
DC – 111
MD – 5
MA – 25
NH – 1
NJ – 10
RI – 1
VT – 1

Offshore - 6

Utilization Normalized to 30-Day Months

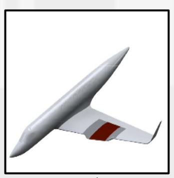


Aeronautics Computational Support (6,231,508 SBUs)



Fundamental Aeronautics
# of projects: 117
# of SBUs used*: 5,894,186

- HECC enabled Subsonic Rotary Wing projects to develop better physics-based computational tools and flow simulations in order to address poorly-understood phenomena in rotorcraft flight, to improve rotorcraft aerodynamic performance and to reduce noise from blades.
- Large simulations on complex geometries were performed to understand the noise radiated from aircraft landing gear in order to develop quieter aircraft.
- HECC supported computationally intensive, time-accurate simulations of receptivity and stability processes in boundary layers to improve predictive capabilities in flows for development of efficient, reliable, and reusable hypersonic vehicles.



Integrated Systems Research
# of projects: 2
# of SBUs used*: 760

- Understand the operational characteristics of fluidic actuators and their effect on flow separation. This helps reduce the size of control surface and the weight of an aircraft.
- Develop and demonstrate usable and robust aero design tools for natural laminar flow to help design aircraft to meet fuel burn goals

Airspace Systems
# of projects: 1
# of SBUs used*: 35,563

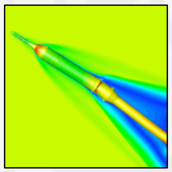
- To help transform U.S. airspace, numerical simulations enhance prediction algorithms used to reduce aircraft separations, increasing arrival/departure rates while ensuring wake vortices from a leading aircraft do not endanger trailing aircraft.

Aviation Safety# of projects: 4
# of SBUs used*: 300,999

- Atomistic simulations were used to predict the effect of moisture, temperature, and cure conditions on mechanical properties of epoxy polymers in order to assess the effect of aging on these aircraft materials.
- Fracture mechanics simulations were performed to predict and characterize damage in both metallic and composite materials, thereby helping to assess damage growth and evaluate the damage tolerance of aerospace structures.

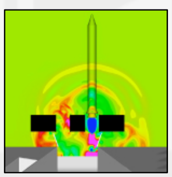
*June 1, 2010 to May 30, 2011

Exploration Computational Support (12,147,328 SBUs)



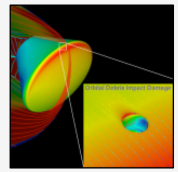
Ares Launch Vehicles
# of projects: 11
# of SBUs used*: 7,765,313

- High-fidelity CFD simulations are enabling detailed analysis of stage separation aerodynamics for the Ares I CLV and Ares I-X Flight Test Vehicle
- Plume analyses assess aerodynamic performance and control factors for Ares I Roll Control System
- Aeroelastics analyses of dynamic ground wind loads assess potential oscillations for Ares I on the launch pad
- CFD simulations of Ares V ascent provide key data supporting vehicle design analysis cycles and assessment of base heating effects



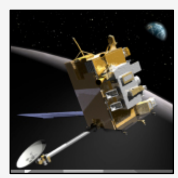
Constellation – Space Launch Systems / Other
# of projects: 12
# of SBUs used*: 859,758

- CFD simulations of SRB ignition inside the Vehicle Assembly Building help determine safety factors for storing Ares launch vehicles in the facility
- CFD simulations of ignition overpressure showed Shuttle Mobile Launch Platform can be used for Ares I



Orion Crew Exploration Vehicle
# of projects: 13
# of SBUs used*: 2,434,132

- Extensive CFD solutions support aerodynamic database of ascent abort and reentry for Orion's critical design review
- Extensive verification and validation of CFD codes establish aerodynamic simulation guidelines for Orion
- CFD simulations determine sting interference and Reynolds number scaling corrections for CEV wind tunnel test data
- Aerothermal CFD simulations of thermal protection system material ground tests and reentry environments are helping optimize Orion's heatshield design



Exploration Systems - General
# of projects: 7
# of SBUs used*: 1,088,125

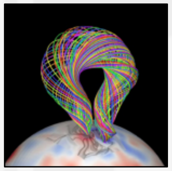
- Simulation of crater formation beneath a lunar lander and dust and debris flow across the surface has been carried out in 2010. This will provide data to aid in selecting suitable landing sites and assist in designing thrusters and flight profiles to reduce the risk of damage to the flight vehicle and surrounding structures and equipment.

*June 1, 2010 to May 30, 2011

Science Computational Support (21,373,349 SBUs)

Earth Science
# of projects: 87
# of SBUs used*: 6,439,690

- HECC is used for increasingly accurate syntheses of available global-scale ocean and sea-ice data to improve understanding and predictive capability of the ocean's role in future climate change scenarios.
- HECC simulations are used to understand how changes in stratospheric ozone impact climate and how changes in climate impact atmospheric chemistry.

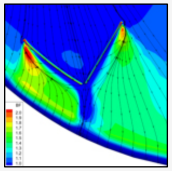


Heliophysics
# of projects: 58
# of SBUs used*: 7,253,522

- HECC runs and interprets high-resolution magneto-convection and coronal mass ejection simulations to enhance understanding of the solar magnetic field, predict magnetic flux emergence, and understand their influence on Earth's magnetosphere to protect U.S. space assets.

Astrophysics
# of projects: 56
# of SBUs used*: 6,511,510

- HECC enabled high-resolution simulations to help understand/explain how structures in today's universe (including galaxies and black holes) were formed.
- HECC enabled 3D radiative transfer hydrodynamics simulations of cosmological reionization to provide a quantitative framework for interpreting observations of the cosmos.

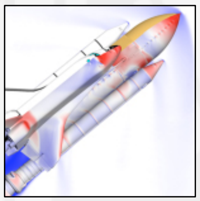


Planetary Science
# of projects: 51
# of SBUs used*: 1,168,627

- Large-scale simulations help answer fundamental questions about the evolution history of planets in our solar system and as well as those in other solar systems and galaxies.
- Simulations help explain how the observed banded zonal winds and dipolar magnetic fields are maintained on giant gas planets and help predict what kinds of planets exist in orbit around other stars.

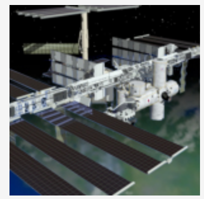
*June 1, 2010 to May 31, 2011

Space Ops & Safety Support (1,088,125 SBUs)



Space Shuttle
\# of projects: 7
\# of SBUs used*: 550,774

- The Shuttle Program relies on detailed simulations to assess aerodynamic/aerothermodynamic environments encountered during missions, including launch and in-orbit debris damage and prediction of debris transport for shuttle configuration changes. Many of these simulations are time-critical and help to assure safe re-entry of the orbiter.
- HECC has enabled unprecedented simulation capability (10K–20K simulations/hr) for creation of automated databases to analyze vehicle design performance for the Space Shuttle and Constellation Programs.
- HECC resources are utilized to evaluate shuttle loads on the International Space Station during shuttle attitude control for mated operations.



International Space Station
\# of projects: 2
\# of SBUs used*: 46,394

- Structural assessment and predictions for ISS module weld strength are calculated for ISS safety analysis.

NASA Engineering & Safety Center
\# of projects: 6
\# of SBUs used* 420,841

- Computational aerodynamics and structural analysis of Max Launch Abort System (MLAS) concepts enable efficient development of the Ares flight test vehicle, including the alternate crew abort system MLAS.
- Extensive, time-accurate CFD simulations provide an efficient, cost-effective assessment of existing ground operations infrastructures to determine and plan modifications required for the Ares launch vehicles.

*June 1, 2010 to May 30, 2011

What Some of Our Users Have Said

"Without the NASA supercomputing resources, these calculations [large computational meshes and complex chemistry models] could not be completed in time to meet the Constellation vehicles' design schedules. High-fidelity analysis codes like DPLR, LAURA and OVERFLOW and NESC resources enable the generation of data that would otherwise be too expensive or impossible to obtain through ground tests."

- *Kerry Trumble, Exploration Systems*

"Time-accurate ... NASA's extensive ..."

- *Cetin Kiris, Exploration Systems*

- *Steven Pawson, Science*

- *Stephen Alter, Space Operations*

"... availability of thousands of CPUs for a single simulation run was crucial for the results presented here."

- *Mark Chun Ming Cheung, Science*

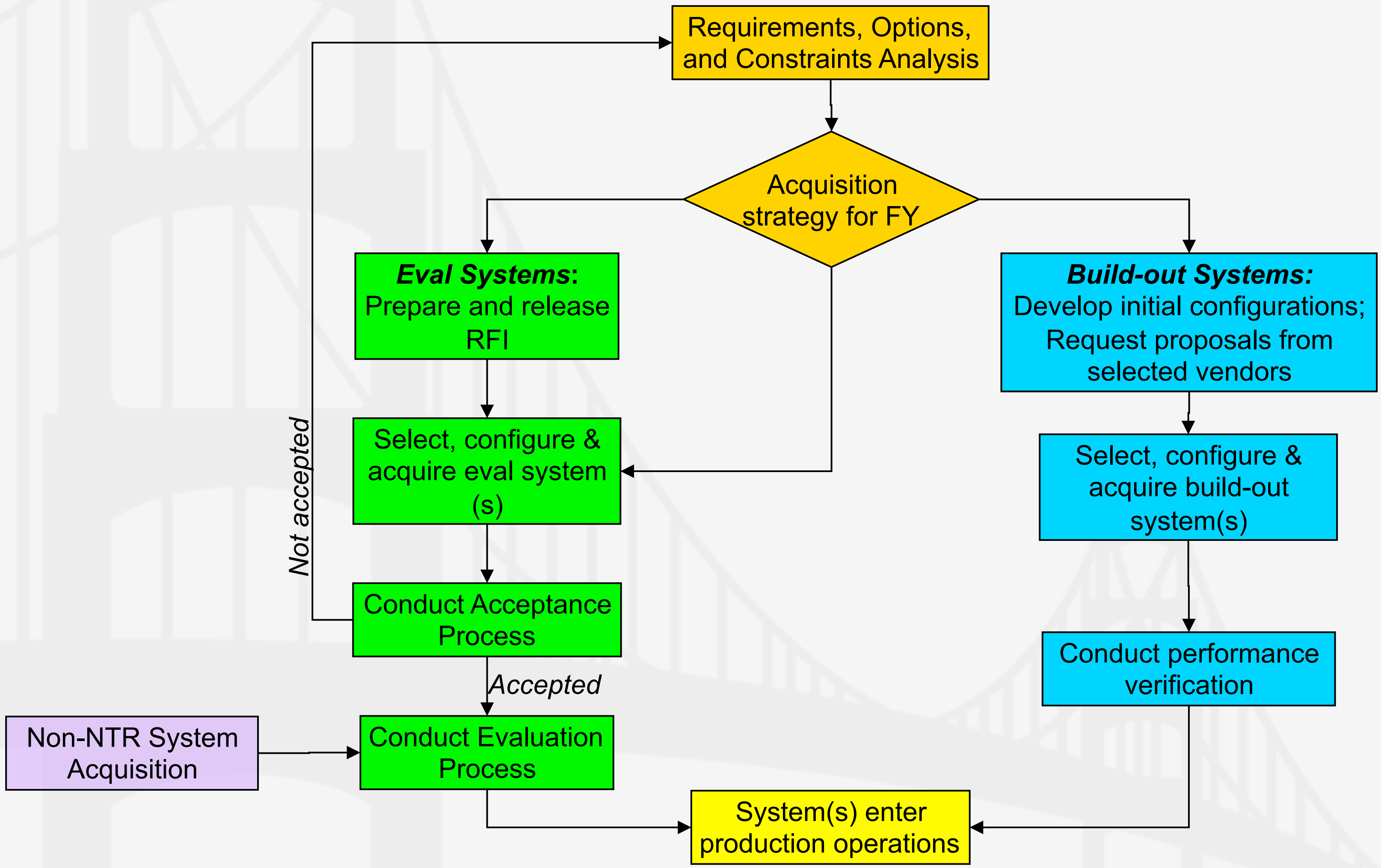
"... A problem of this scale could not be resolved on a ... The speed and processor availability of Pleiades allows us to obtain solutions in reasonable time limits."

- *James Kless, Exploration Systems*

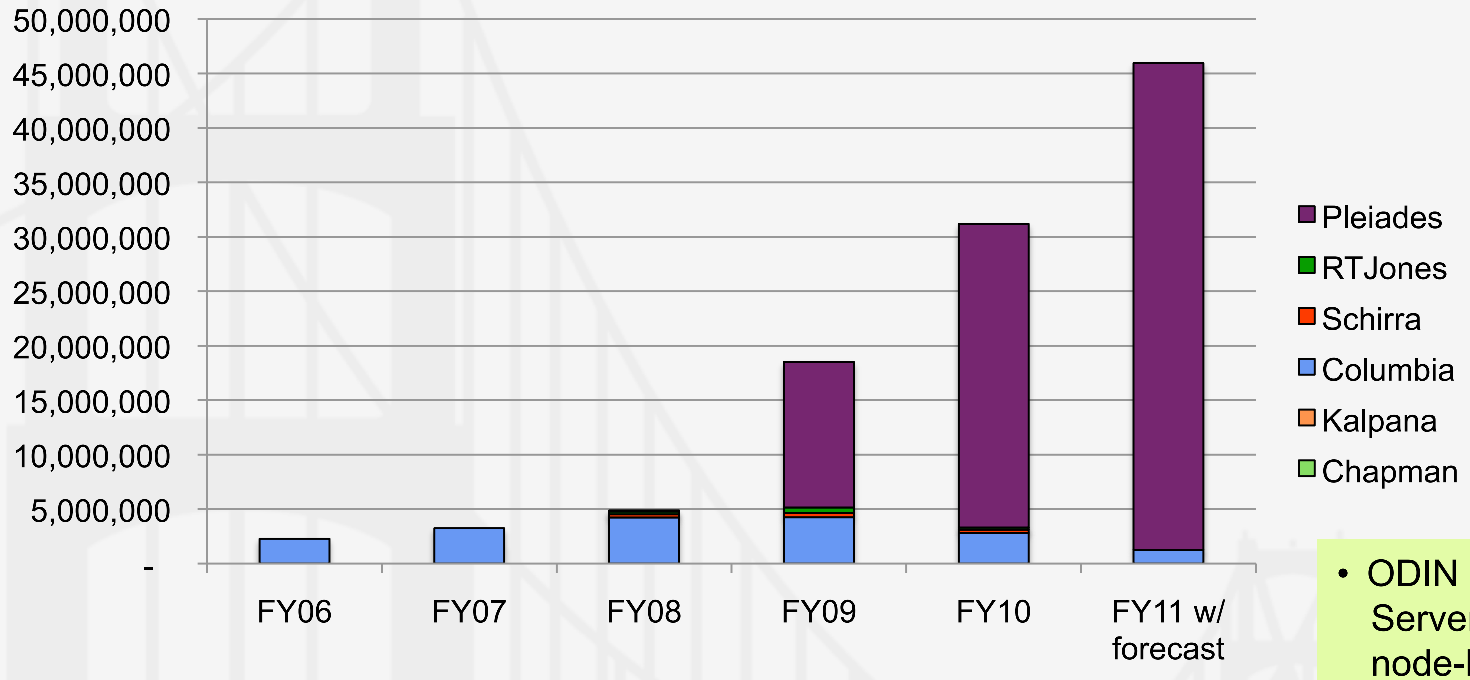
NAS Technology Refresh Strategy: Overview

- Determine the optimal major acquisition approach (architecture mix, vendors, …)
  - Understand NAS HEC environment (systems/architectures, users, utilization, facilities, archive and network infrastructure, etc.)
  - Understand the technology landscape and future roadmap
- Reduce risk with new architectures and accelerate transition to production by building expertise on evaluation systems
  - Increase the diversity of viable build-out architectures/vendors
  - Increase vendor competition for NASA business (and thus increase the HEC capability acquired per dollar)
- Build out systems as driven by stakeholder requirements
- Leverage symbiotic partnership with vendor(s)
- Utilize a flexible and adaptable process that can be customized to seize compelling opportunities

NTR Overview: Annual Process



Return on Investment



$ / SBU	**17.29**	**11.21**	**7.74**	**2.20**	**1.34**	**0.89**

- ODIN Entry-level Server is $9.36 / node-hour if used 160 hrs/month
- SGI charges $4.00 / node-hour
- Amazon charges $1.60 / node-hour

CONCLUSIONS

Advantages of Current HECC Model

- NASA owned and supported in-house HEC resources
  - Integrated support to NASA scientists and engineers, not just bare cycles as available from third-party external vendors of compute cycles
  - Push the technology (and HEC vendors) to meet NASA's evolving HEC requirements (e.g. large shared-memory systems, InfiniBand hypercube interconnect, utilization of COTS hardware, open-source software)

- NASA-wide consolidated HEC resources
  - Leverage expertise to serve the entire Agency's M&S requirements – provides better support for acquisition and management of resources
  - Balances demand and utilization across users from all NASA projects (meets dynamic peak demands of critical projects without having to maintain project-owned resources)
  - Projects do not pay directly for baseline cycles and support, making it easier for them to use resources without cost issues (MDs control allocation according to their project priorities)

HECC Well Managed and Wisely Used

Achieves 3 core objectives as specified in HEC Program Plan

- Frequent communication with NASA stakeholders
  - 6-10 highlights/month to HQ and Center management
  - Monthly reports to HECC Portfolio Manager
  - Quarterly reports to SCAP management
  - Biennial HEC mission impact report to all stakeholders
  - ~Biennial review of NTR procurement process
- Comply with Federal and NASA requirements for project and IT management
  - 7120.5D-compliant Project Plan, System Engineering Management Plan
  - Participation in annual PPBE budget exercises
  - Annual OMB Exhibit 53 and Exhibit 300 reports
  - NIST-compliant IT security plan
- Communicate externally the contribution of HEC to NASA missions
  - Press releases, biennial HEC mission impact reports, NAS and HEC websites
  - NASA booth at annual Supercomputing conference
  - Interagency coordination (e.g. NITRD, HEC-IWG, IIWG)
  - Educational outreach (e.g. facility tours, intern HEC users)
  - Public outreach (e.g., facility tours, booth at local events)

HECC Well Managed and Wisely Used

Pursues continuous improvement and develops best practices

- Expert support services: Efficiently solve user problems and increase user productivity, multiplying value of HECC resources
- hyperwall and concurrent visualization: Dramatic new insight into models, codes, and massive data, accelerating science and engineering
- NAS Technology Refresh: Procurement process ensures most productive resources possible within budget
- Vendor partnerships: Help improve advanced technologies, obtain excellent prices and service, and minimize risk of integrating leading-edge systems
- Root Cause Analysis: Customized process ensures continuous improvement of resource availability and reliability
- User requirements: Periodically gather user needs and expectations through surveys, requirements workshops, etc.
- Usage Reporting: Automated chart and slide generation using MicroStrategy
- Further automation of repeating activities: IT security, usage/utilization reports, advanced queueing, network flow monitoring, and more

Unique HEC Contributions

- Large shared memory supercomputing: World's first 128, 256, 512, 1,024, and 2,048-core Single System Image (SSI) deployments
- Large InfiniBand supercomputing: Pleiades is the largest InfiniBand cluster (using Open Fabrics)
- Rapid deployment: Record-setting pace of bring complex systems to operational status has set the standard for industry
- hyperwall pioneers: LCD arrays for large-scale data analysis and visualization
- Concurrent visualization: Analysis and rendering at a scale and frequency not otherwise possible, for ultimate insight into models, codes, and results
- HEC benchmark suite: Developed, maintained, and continue to enhance NAS Parallel Benchmarks (NPB)
- Supercomputer job scheduling: Developed Portable Batch System (PBS) scheduler (now commercialized and industry standard)
- Leveraging vendor partnerships: Unique industry/government approach enables HECC-vendor team to rapidly resolve challenges and deliver productive systems at a fraction of the costs at other leading sites

Coordination and Strategic Alliances

Coordination and cooperation with external organizations is key to innovation, cost-efficiency, and high performance

- NAS / HECC provides NASA reps to NITRD, HEC-IWG, CSIA, SDP: multi-agency efforts to solve major, long-term HEC and broader IT challenges
- NAS / HECC participates strongly in other community, National, and global initiatives to ensure NASA benefits from new ideas and supporting activities
  - Open Fabrics Alliance: advancing InfiniBand as HEC interconnect
  - Lustre partnership with LLNL and ORNL
  - Interagency Infrastructure WG (IIWG) for Aeronautics R&D
  - SBE&S, HECRTF, HPCMOD, HPCS, Exascale, SCIDAC, NSF Blue Waters, etc.
- Vendor partnerships help improve advanced technologies, obtain excellent prices and service, and minimize risk of integrating leading-edge systems
  - Intel, SGI, NVIDIA, Mellanox, etc.

HECC fosters these strategic alliances via robust participation

- Technical conferences: Supercomputing, Salishan, IPDPS, SIAM, AIAA, ICCFD, etc.
- High-level meetings and strategizing with other agencies
- Joint problem solving with hardware and software vendors

Summary

No question…NASA has:

- Supremely challenging missions to greatly extend the boundaries of human knowledge and achievement
- Expert users (world-leading scientists and engineers) who need, expect, and can fully utilize advanced M&S to lead the pursuit of those missions
- Unparalleled technical capability (expertise and infrastructure) to remain a world-class HEC provider

The real question: How can NASA meet its mission-driven HEC requirements most cost-efficiently, reliably, and for long term?

HECC has stepped up to the challenges, pioneered solutions, and delivered mission impact through and with our users beyond the performance of any other HEC facility in the world!

Questions